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CARPINTERIA, CALIFORNIA

LARGE-DIAMETER ASTROMAST DEVELOPMENT, PHASE II FINAL REPORT

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SECTION 1
INTRODUCTION

This report describes the work done in the second phase of a contract between Astro Research Corporation (Astro) and NASA Marshall Space Flight Center (MSFC). This effort was culminated by the delivery of a 15-m-long by 0.75-m-diameter deployable Supermast* shown in Figures 1 and 2. The performance characteristics, design parameters, and developmental work associated with this mast are described herein. The previous Phase I final report (ARC-TN-1119) described similar information relating to a 6-m-long test section which has already been delivered to MSFC.

The main differences, besides the length of these two mast sections, are a change in the longeron material (the principal structural member) to a circular cross section and the incorporation of a lanyard-bridle system which makes unaided deployment and retraction possible in zero gravity.

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*Supermast is a trademark for a double-laced Astromast. The Astromast is proprietary to Astro (U.S. Patent Nos. 3486279 and 4434391).

SECTION 2
TECHNICAL DESCRIPTION

2.1 GENERAL INFORMATION

The hardware delivered consists of two main components: a 15-m-long section of Supermast which is approximately 0.6-m long when stowed and a base support/winch stand which is used for 1-g testing.

The mast test section is the only portion of this assembly which is representative of spaceflight hardware. The end plates, bridle assembly, and winch stand are all designed for functional verification and would either be redesigned or not necessary for a flight application.

The high aspect ratio (67:1) of the extended mast combined with the weight of the tip plate (60 pounds) and the weight of the mast itself (200 pounds) must all be considered when deploying and retracting the mast in a 1-g environment. Astro tried several methods but recommends mounting the mast so that it may be extended vertically downward. A complete operation manual for this mode was prepared and submitted with the mast (see Appendix A). Although other modes of operation are possible, they require additional fixturing and gravity compensation devices.

2.2 SPECIFIC DESIGN INFORMATION AND CALCULATED PERFORMANCE PARAMETERS

The basic design parameters associated with this mast are presented in Appendix B. The predicted bending strength and bending stiffness of the delivered mast are 4700 N-m and 1.3×10^6 N-m^2, respectively. The measured mass per unit length of the mast is 3.43 kg/m without tip plates and bridle.

SECTION 3
PROGRAM MILESTONES, CHRONOLOGICAL SEQUENCE

3.1 MATERIAL PROCUREMENT

3.1.1 Longeron Material

Procurement of suitable material for the longerons in 50-foot-plus lengths proved to be difficult in this phase of the program. The relatively small quantity but high quality necessary for this application is in great contrast to the high quantity, commercial-grade orders that major pultruders of this material are accustomed to dealing with. As a result, 800 feet of material (in four batches of 200 feet each) was eventually procured to obtain 150 usuable feet with a 50-foot spare section. The following is a summary of this activity.

3.1.1.1 BATCH 1

This materal tested extremely low on Astro's material evaluation receiving inspection strain limit test (1.95 percent compared to an expected 2.8 percent). Consultation with the vendor (Goldsworthy Engineering) revealed that an incorrect mold release had been used which resulted in replacement of this batch by the vendor.

3.1.1.2 BATCH 2

This material also developed much lower than required strain capability (approximately 1.8 percent). Further consultation with the vendor revealed that he had not used an rf induction heater during the pultrusion of the material, a significant deviation from the previous production process used to fabricate the material for the Phase I 20-foot mast. Astro postcured this material and used it to assemble the 50-foot mast. The marginal strain capability of the material resulted in longeron failure in the stowed condition.

3.1.1.3 BATCH 3

This material was obtained from another vendor (Glassforms, Inc.) because of the failure of the first two batches to meet strain limit requirements. Although the strain limit of the material was acceptable, the material was damaged in shipment due to inadequate shipping containers so that only one of four pieces was usable. Also, the vendor used a mold release new to them for this run (which Astro was unaware of), which subsequently proved difficult to bond to.

3.1.1.4 BATCH 4

The vendor replaced the damaged material and packaged the new rods; however, even with extra precautions, one section of these four had to be rejected due to flaws incurred by shipping. Although it was desired to use three sections from the same batch, one of the three usuable sections from this batch was pulled from production after the bonding of pivots was approximately 80 percent complete. It was discovered that the pivots had been fabricated from the wrong material and were considerably weaker than those made of 6061T6 aluminum. Rather than attempt to reclaim the longeron by removing the pivots or by ordering more material, the decision was made to use the one remaining longeron from Batch 3. This resulted in the change in the bonding procedure for the pivots because the mold release used in Batch 3 material was extremely difficult to bond to and required extensive sanding to ensure a good bonding surface.

Characteristics of the final (Batch 4) material are as follows:

o Averaged glass content, by weight	80.2 percent
o Modulus of elasticity	56.9 GPa (8.3 x 10^6 psi)
o Nominal diameter	11.3 mm (0.445 inch)
o Maximum strain capability (without noticable effects on any sample)	2.7 percent
o Average strain capability (four samples)	3.1 percent

All material was successfully proof tested by passing over a 0.5-m-diameter mandrel, which represents a flexural strain of 2.2 percent, prior to bonding on the pivots.

3.1.2 <u>Batten Material</u>

The batten material was pultruded, rounded-rod, S2-glass/epoxy composite. Because of the smaller diameter and short lengths, procurement was straightforward. The results of Astro's evaluation tests are as follows:

o Nominal diameter	7.87 mm (0.310 inch)
o Flexural modulus of elasticity	57.4 GPa (8.33 x 10^6 psi)
o Percent voids (calculated)	3.06

o Composite density	1.988 gms/cc
o Strain limit (5-inch radius of mandrel)	3.0 percent

In addition, the surface is extremely smooth and glossy.

3.1.3 Diagonal Material

The diagonal material was pultruded, round-rod, S2-glass/epoxy composite with the following parameters:

o Nominal diameter	3.68 mm (0.145 inch)
o Flexural modulus of elasticity	57.7 GPa (8.37 x 10^6 psi)
o Percent voids (calculated)	7.09
o Composite density	1.862 gms/cc

3.2 DEPLOYMENT/RETRACTION BRIDLE DEVELOPMENT

Development of a lanyard bridle arrangement proceeded in parallel with the fabrication of the 50-foot model. The development work was done on the 12-foot engineering model previously built by Astro. Although the original layout for this system was done early in the program, several stages of developmental, or "tuning," work were necessary before the final configuration was achieved. The main function of the bridle is to allow unassisted retraction of a fully deployed mast by initiating a helix in the tip of the mast when lanyard tension is applied.

3.3 TRADEOFF OF MAST STIFFNESS AND DEPLOYMENT CHARACTERISTICS

It was observed early in the program that if the mast components were sized for maximizing the deployed mast stiffness, developmental work outside the scope of this program would be necessary to achieve normal Astromast deployment/retraction capabilities. Even after reducing batten and diagonal cross sections in Phase I, some additional developmental work was necessary to minimize the end effects. Sliding pivot mounts were provided for the end pivots to reduce the end effects on the deployment characteristics. In addition, several half-strength batten frames were included in the end bays to balance diagonal forces and further reduce the end effects. Once these had been installed, it was observed that even though the mast could operate adequately, the bias in the batten frames was not enough to ensure that they buckled in a symmetrical manner when passing through the transition region of the mast. Consequently, the midpoints of each batten were interconnected with light wire to ensure that all battens buckle in the same direction. More information on the development of these devices can be found in Section 4.

3.4 ASSEMBLY AND CYCLING

After the first assembly and test cycles, the longerons delaminated because of the unsatisfactory strain limit of the Batch 2 material. The longerons were replaced and retested. The pivots on one longeron slipped after a few cycles, and that longeron (from Batch 3) was removed and the pivots all pull tested and repaired. Aside from some delaminations attributed to mishandling, the remainder of the test program proceeded smoothly. A complete record of cycles to date is presented in Appendix C.

SECTION 4
COMPONENT DEVELOPMENT

4.1 SLIDING TERMINAL ASSEMBLIES

Repeated difficulties with the 12- and 20-foot masts in the end regions of the mast prompted development of a device to reduce the end effects. Although the 20-foot model could be retracted and extended without damaging the mast, it was felt that the deployment characteristics were marginal and that the high loads induced by the diagonals rubbing against each other impeded the deployment and reduced the excess lanyard tension (e.g., deployment force) to nearly zero. With sliding end terminals installed, the diagonals still make contact with each other, but the tensions in the diagonals are dramatically reduced by allowing the mast to contract at the end bay. The drawing for the sliders was made in March 1983, and they were first implemented in the rebuilt 12-foot mast during July 1983. The design was refined with the addition of stops to limit excursion in the sliders in October 1983 (see Figure 3).

Both Teflon and Delrin slider guides were fabricated. Neither showed any particular differences in operation or performance.

4.2 BRIDLE OVERRIDE

When the 12-foot mast was assembled with the original bridle arrangement, it was observed that retraction stopped at the beginning of the retraction of the third bay and lanyard tension increased without a corresponding movement of the tip plate. It was felt that further application of tension would result in serious damage to the mast. Consequently, the trifilar bridle is used just to initiate the helix into the longerons. Once this has been accomplished (after retracting approximately 18 inches), an override on the lanyard engages the tip plate and applies a compressive load. This removes the high shear load from the longeron at the point of attachment of the bridle and reintroduces the load into the end terminal where it is carried for the remainder of the retraction (or until the first bay is fully retracted and the load is then carried through the battens in the stack as well). This device was first installed on the 12-foot mast in October 1983. The 12-foot mast was tested with the override and the results are presented in Figure 4. Lanyard tension necessary to operate the bridle to initiate the helix into the mast is shown in Figure 5.

4.3 BATTEN INTERCONNECTING SYSTEM

During the development work on the 12-foot mast with the self-retracting lanyard system, it became apparent that under certain circumstances, a batten flipping in an asymmetric manner could prevent deployment. Furthermore, it was evident from observation and "feel" (when handling the mast manually) that the internal loads developed in the diagonals and longerons were much higher when the battens flipped asymmetrically and interfered with each other at the midpoints of each batten member at maximum deflection.

A device to prevent this was implemented which relies on interconnecting the batten members so that as one reaches its maximum deflection it influences the adjacent batten which is still in a low deflection state. This system does presuppose, however, that the initial batten in the sequence is correctly formed, which at this point must be done manually. (See Appendix A, Section 4, Phase 1.) This system was developed on 21 October 1983 (Ref. Astro Logbook 1023, Pg. 33) and first implemented on the 12-foot mast (see Figure 6).

4.4 DIAGONAL LUBRICATION

At various stages in the development of the 12-foot mast, diagonals were damaged and replaced. After extensive cycling (approximately 25) for the development of the bridle, however, no further diagonal damage was observed. After the 50-foot mast was first assembled, four diagonals failed on the first retraction. It was not felt that these were related to the failure of the longeron assemblies in the first 50-foot assembly but rather to the tendency of the diagonals to form a kind of woven pattern in the transition region during retraction and/or extension. Although further cycling may have "weeded out" or smoothed out the diagonals, it was felt that this situation would benefit from lubrication. This was first tried on the 50-foot mast when the entire set of diagonals was sprayed with a commercial Teflon spray lubricant. Although the lubricant was runny after application and tended to bead up on the lowest portion of the mast, the operation of the diagonals was significantly improved and the action of the transition region seemed much more regular and controlled.

4.5 PIVOT DESIGN

Although successful performance had been obtained on both the 12- and 20-foot models with the original pivot design when the longeron material was changed to a round cross section, the bond line area had to be reexamined because of the difference in clearance between the octagonal and round cross sections. Astro has attempted to maintain bond lines of approximately 0.006 to 0.008 inch in this application (pivot/longeron joint). In this case, however, (because of the earlier difficulties with longeron failures at the joints) we were wary of going immediately to a joint designed totally for strength rather than flexibility. For this reason, the thin bond line was only developed in the center portion of the pivot, and the chamfer from each end was increased so the longeron could flex through the joint more easily. No problems have occurred to date with this design. The pivot bond failures which were encountered were explained by the presence of a different type of mold release used in the manufacture of that particular longeron.

SECTION 5
FOLLOW-ON WORK SUGGESTED BY PHASE II

5.1 END TERMINAL REDESIGN

During the course of the program, the most consistently troublesome area was the section of longeron between the end fitting and the first pivot. Delaminations along the neutral axis have occurred on every mast model and seem to be most affected by mishandling or misalignment due to the presence of inadequate ground support equipment.

The suggested remedy to this would be to redesign the end fitting so that instead of the longeron terminating just above the hinge axis of the terminal pivot the longeron continues through the terminal and the fitting becomes a trunnion. This means, of course, that when deploying, the free end of the longeron would swing in an arc through the plane of the base plate for a distance of approximately one-half bay length. Since the space beneath the base plate generally contains the deployment mechanism and motor, this approach would not have a serious impact on the envelope requirements.

5.2 USE OF MOVABLE LIFTING SUPPORT FOR VERTICAL DEPLOYMENT

A modification of the test plan presented in Appendix A is suggested as an alternative to mounting the base plate to a support 55 feet above. In this plan, a crane with sufficient height would be used to lift the unit as it is being extended downwards. The base would then rise as the unit is extended so that the transition region is always at about eye level for adjustments and/or observations.

5.3 DIAGONAL FRICTION

Since lubrication of the diagonals considerably improved the operation of the mast, some means of doing this in a more effective manner on the next mast should be considered. The suggested solutions included Teflon coatings, dry-film lubricant, or the use of wire diagonals to eliminate the contact forces.

5.4 MATERIAL PROCUREMENT SPECIFICATION

This area needs to be fully explored with the intended vendor before any further material is obtained. While the vendor has shown willingness to accept higher standards on his finished product, no vendor that we are aware of will test material for strain limit or flexural modulus of elasticity. An acceptance test procedure should be developed at Astro and furnished to the vendor before the order is placed so that he is aware of the importance of details such as lack of surface flaws. This acceptance test procedure should include the following as a minimum:

- o Determination of glass fiber content, specific gravity, and calculation of void content
- o Request for all lab run logs from vendor and verification of use of approved materials and procedures, including mold release, curing cycles, pull rates, glass volume, and resin bath temperatures. Though some of this information may be proprietary with the vendor, as much as possible should be learned about each run and recorded for reference
- o Perform strain to failure by using hydraulic ram and bending mandrels developed for this program
- o Pass all material over a suitably sized rolling mandrel to proof strain all the material. The strain limit imposed should be 2.2 percent.
- o Sample pivot joints should be pull tested to ensure the adhesion of the epoxy to this new material. Pivot joints should withstand longitudinal shear loads of 765 pounds. Special jaws have been fabricated to handle these pivots.
- o Thoroughly inspect all material to be used for any surface defects before and after the rolling mandrel proof test. Criteria on these defects depend on their severity, location in the mast, size, type, and cause. Some superficial blemishes and fiber dislocations and/or delaminations can be tolerated in a structure such as the Astromast and not affect performance or function.

5.5 BRIDLE TENSIONERS

One feature of the bridle override system is that, whenever the mast is retracted, the three cables go slack and could possibly become entangled in some portion of the mast. An elastic cord or tensioning device has been fitted to each portion of the bridle. Although these function adequately, they are not recommended for severe usage and could easily be replaced by a constant-force, flight-quality "negator spring" motor assembly if necessary. A suitable unit is ML2920 B motor assembly which is obtainable from Stock Drive Products, San Carlos, California (415-594-1222).

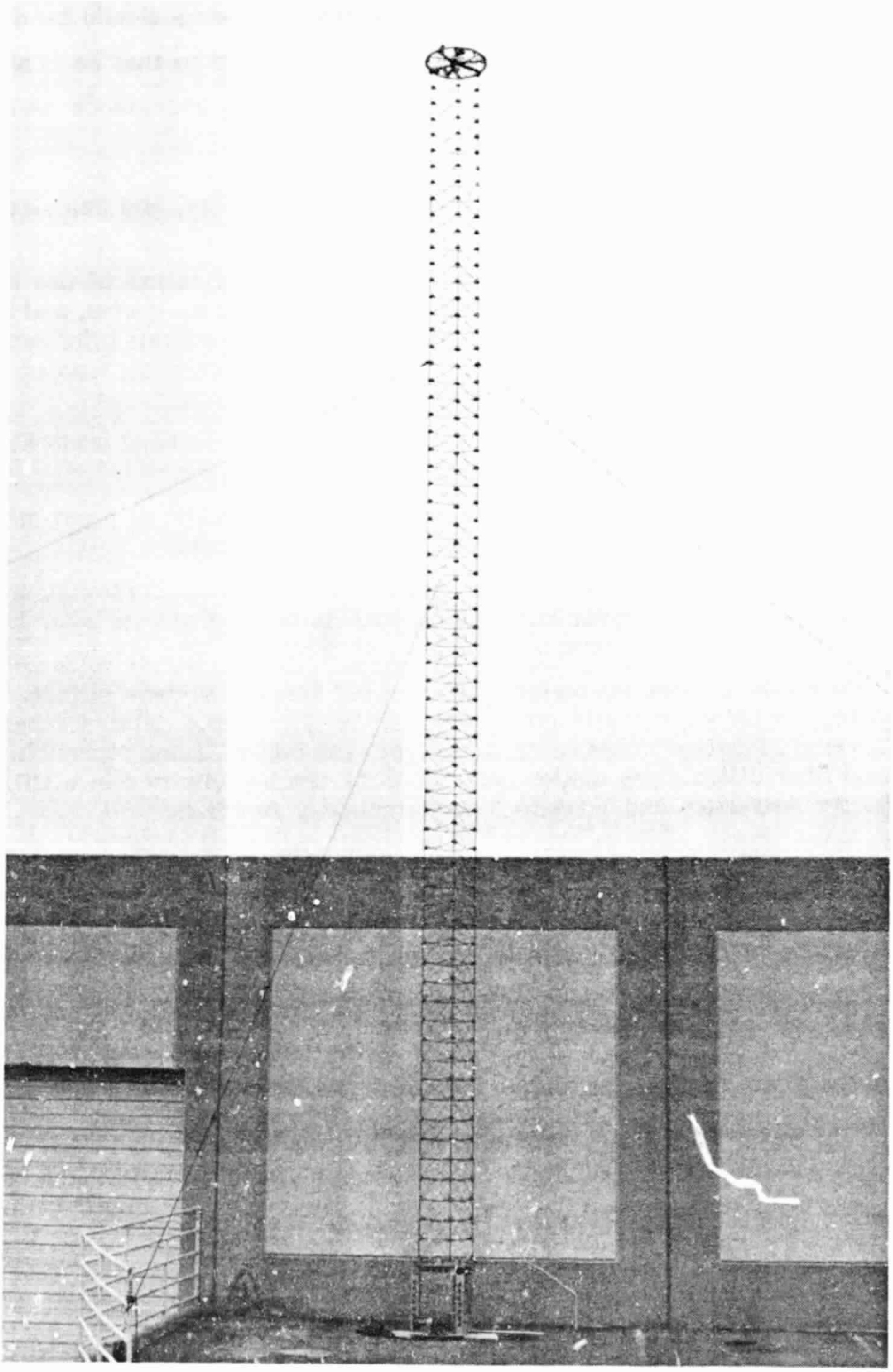

Figure 1. Double-laced Astromast (0.75-m diameter, 15-m long).

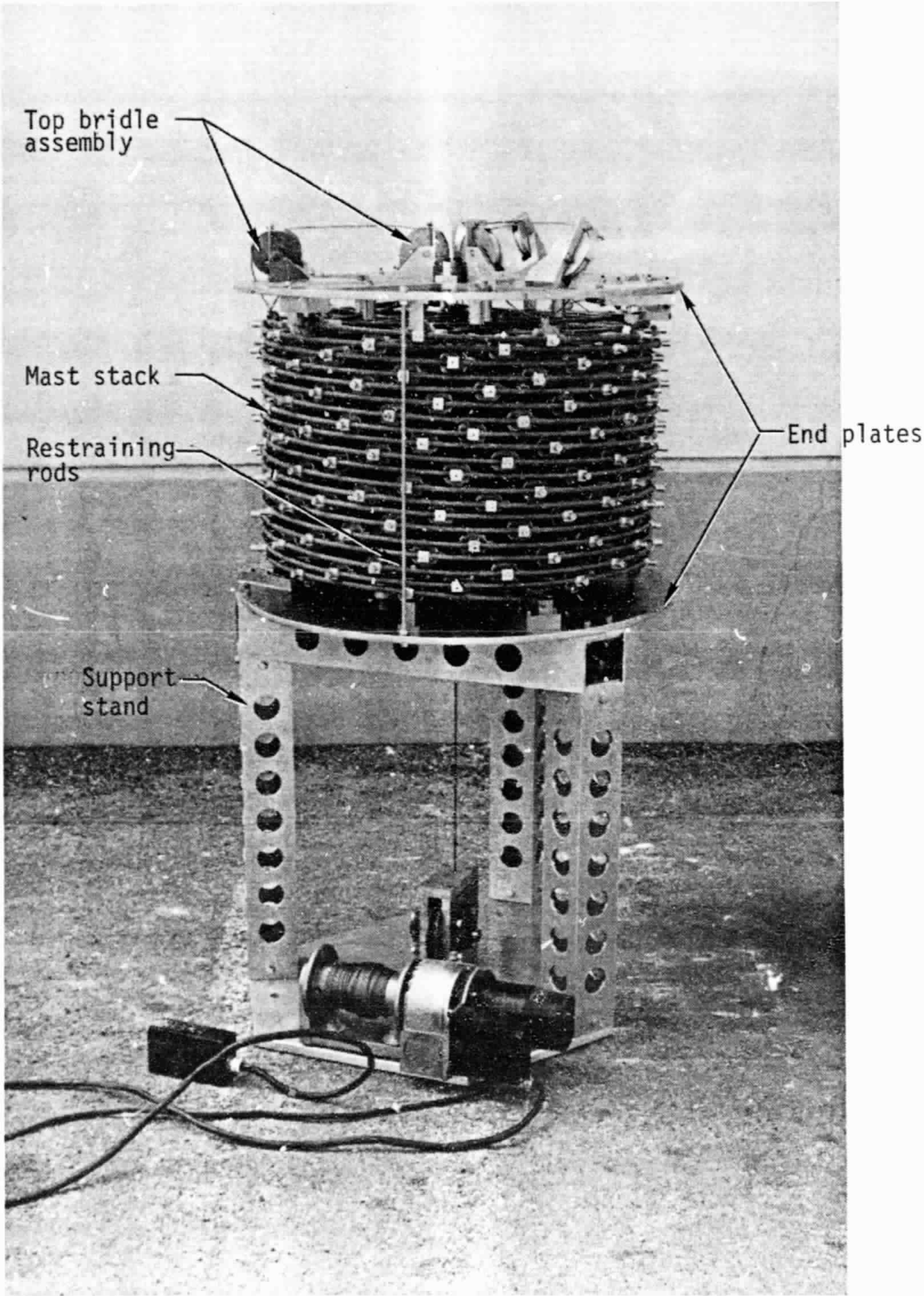

Figure 2. Double-laced Astromast in stowed configuration
(0.75-m diameter, 15-m long).

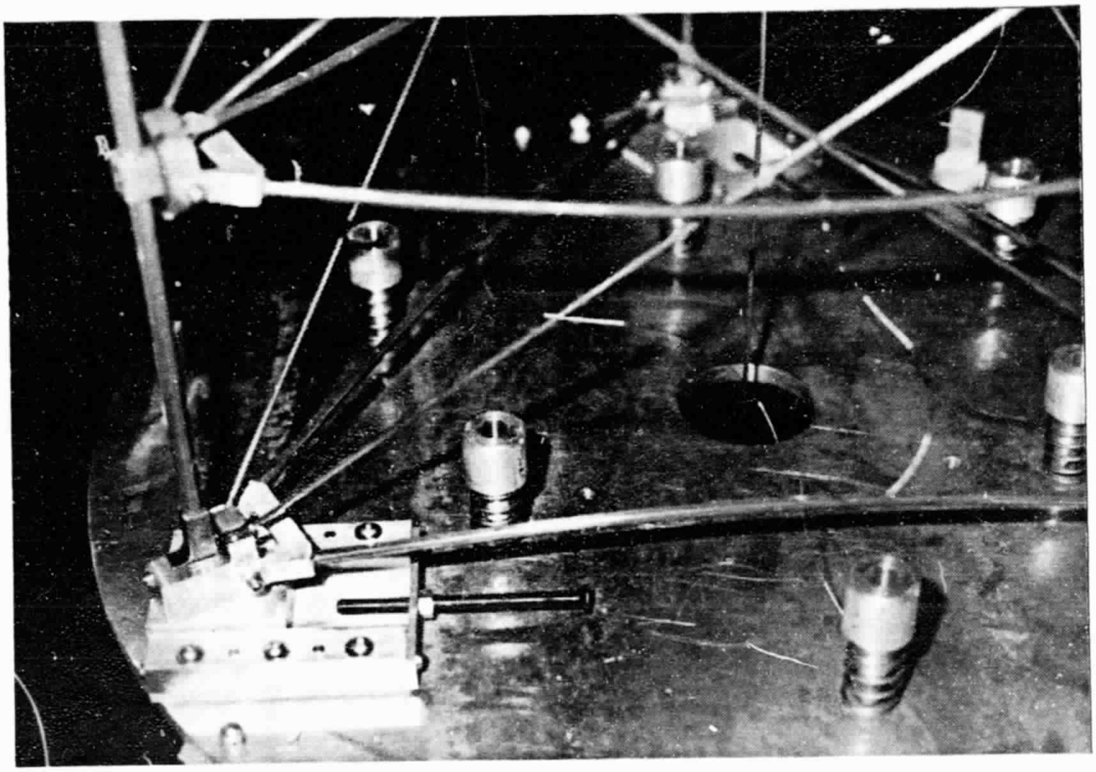

Figure 3a. Base plate slider detail (travel is limited to approximately 1 inch). P065

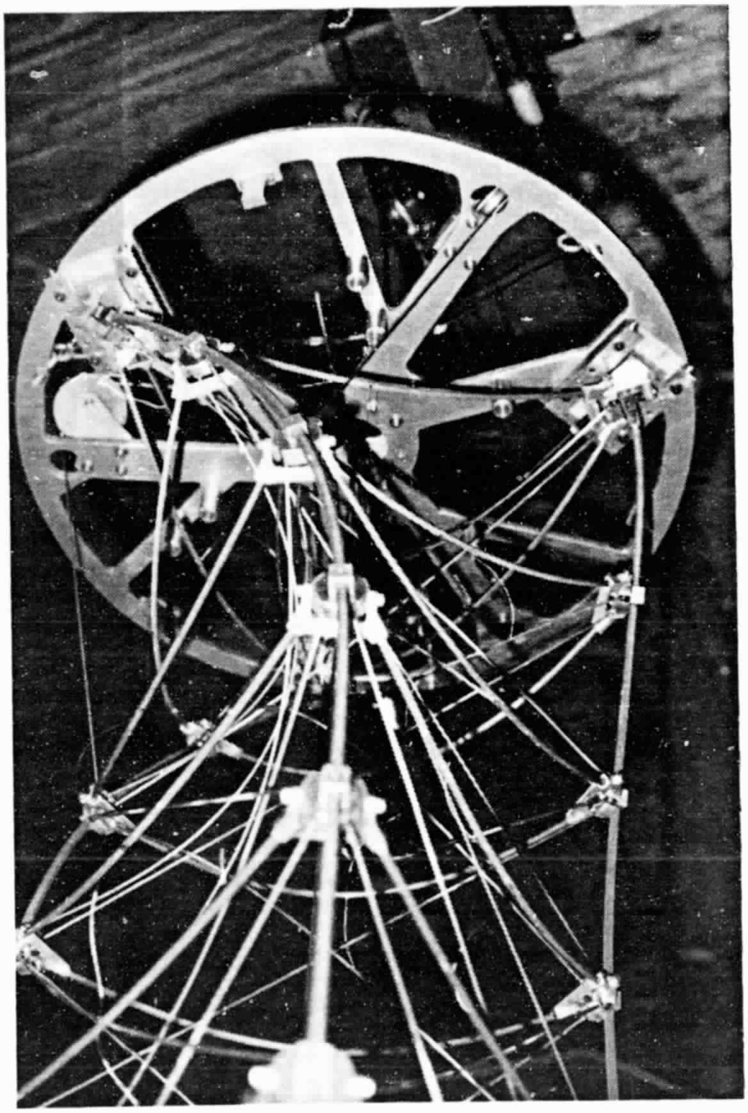

Figure 3b. Inboard position of sliders as transition region reaches the tip.

P066

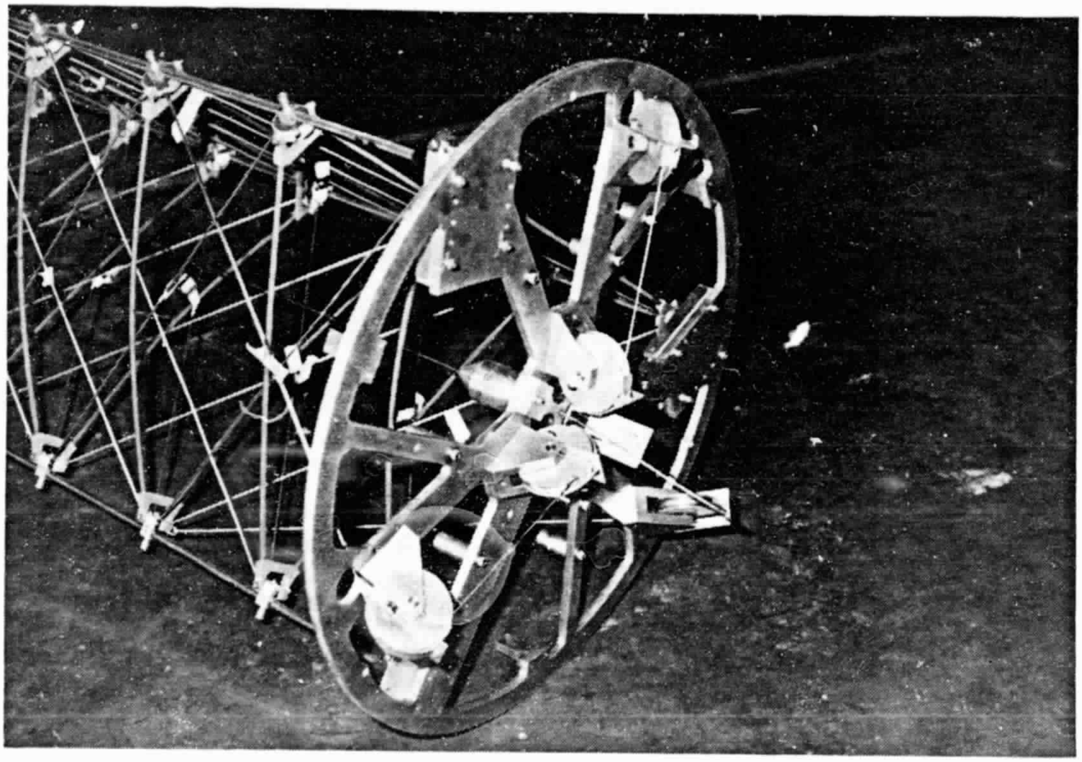

Figure 4. Details of tip plate bridle assembly. *P067*

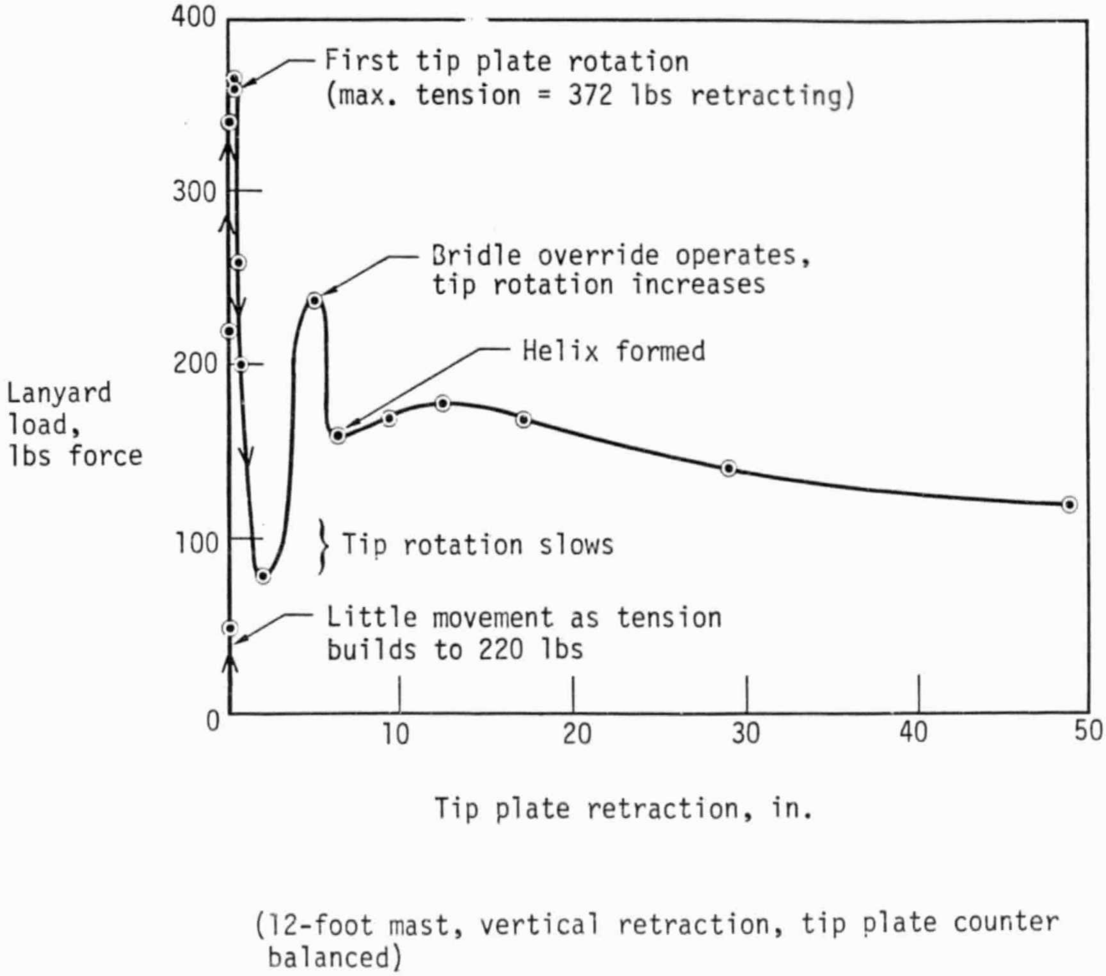

Figure 5. Lanyard tension vs. tip plate retraction.

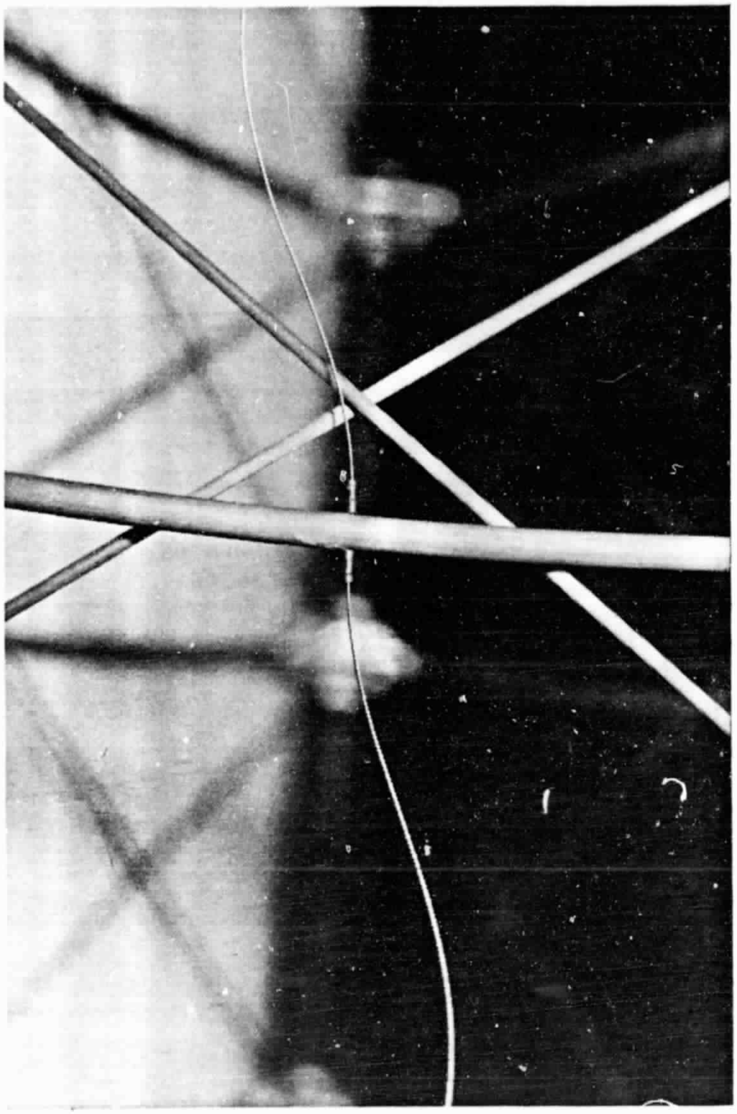

Figure 6. Detail of batten interconnecting system. P068

APPENDIX A

OPERATING INSTRUCTIONS

OPERATING INSTRUCTIONS
FOR
THE 0.75-m-DIAMETER BY 15-m-LONG
SUPERMAST MODEL

ARC-M-1017

1 June 1984

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OPERATING INSTRUCTIONS FOR THE 0.75-m-DIAMETER BY 15-m-LONG SUPERMAST IN A VERTICAL-DOWNWARD ATTITUDE

CAUTION:

This structure is intended to deploy in a zero-gravity environment. Operation in one gravity may induce abnormal loading modes more severe than those foreseen in any expected application. The procedures set forth here alleviate the most severe of these loads by partially simulating a zero-gravity environment and should be followed precisely.

SECTION 1: UNPACKING

The packing container is reusable and designed for use with an overhead lifting apparatus. The lid surrounds the mast assembly and is attached around its lower edge to a forklift pallet. Once the screws holding the lid are removed, the four lifting eyes on the top are used for lifting the lid (see Figure 1).

NOTE: The eyes on the top of the crate are for lifting the lid only. DO NOT ATTEMPT TO LIFT THE ENTIRE UNIT WITH THESE EYES. Once exposed, the unit may be removed from the pallet by removing the bolts holding the baseplate to the wooden pallet. Forks may then be inserted under the top surface of the support stand to lift the unit off the pallet. Once free of the shipping container, the unit can be operated in any orientation; however, as with the 20-foot mast previously delivered, each orientation requires a different setup.

This guide will only describe the vertically downward mode. If any other orientation for cycling is to be attempted, Astro Research must be contacted.

SECTION 2: MOUNTING THE UNIT FOR VERTICAL DOWNWARD CYCLING

2.1 INVERTING THE UNIT

Once free of the shipping container, provision must be made to allow the unit to be inverted. Slings may be attached to hard points on the winch stand to allow rotation to a horizontal attitude. This may also be done manually if necessary. The entire assembly weighs approximately 425 pounds and can generally be handled by three men as long as part of the load is resting on a solid surface.

Once access to the bottom surface of the baseplate is obtained, a screw eye (found threaded into the top surface of the baseplate near its center) may be inserted in the bottom. The entire unit may be hoisted by the secured eye until it is vertical and upside down.

2.2 ATTACHING THE UNIT

Once inverted, the unit may now be raised to a platform at least 55 feet above the nearest obstruction. The base of the winch stand should be firmly attached to a solid support and be horizontal to within at least 1/16 inch across its width (see Figure 2).

2.3 ACCESSIBILITY REQUIREMENTS

Once mounted, some means of access should be provided to the first 1C feet of the deployed mast for handling and/or observation.

SECTION 3: PREPARATIONS FOR DEPLOYMENT

3.1 ELECTRICAL/CONTROL REQUIREMENTS

A control box is permanently atached to the winch. The switch marked "IN" and "OUT" controls the direction of the winch rotation and corresponds to retraction and extension in terms of mast movement. The switch marked "BRAKE" and "RUN" corresponds to off and on.

CAUTION:

DO NOT ATTEMPT TO CHANGE DIRECTION WHILE THE SWITCH IS ON "RUN." THE CONTROL MUST BE SWITCHED TO "BRAKE" TO CHANGE THE DIRECTION SWITCH.

3.2 POWER REQUIREMENTS

The maximum rate of lanyard deployment or retraction (and, consequently, tipplate movement) should be approximately 1 inch per second. This can be achieved by adjusting the input voltage to the winch, which is designed to operate at 120 V, 50 Hz. A variable voltage source such as a Variac can be used for this purpose. The maximum voltage necessary is about 55 Vac with the average demand being about 40 Vac.

To operate the mast, the method recommended by Astro is to first select the direction of mast movement at the control box. Then the "RUN" switch is selected, and only then is the voltage increased until the mast is moving at the correct rate. DO NOT OPERATE WITHOUT CONTROLLING THE INPUT VOLTAGE TO THE WINCH.

3.3 OPERATION AT END OF CYCLE

There are no <u>LIMIT SWITCHES</u> on the winch control. At full mast extension the lanyard will grow more slack after full deployment is reached until the voltage is reduced to zero or the "BRAKE" position is selected. When retracting, however, the opposite is true. The stack becomes fully compressed when the tipplate and baseplate are approximately 29-1/2 inches apart and the lanyard tension increased rapidly. SERIOUS DAMAGE WILL BE DONE IF THE RETRACTION IS NOT STOPPED BEFORE THE STACK IS FULLY COMPRESSED. Astro suggests that the threaded rods be used as guides and that retraction is continued just far enough to allow the nuts to be started at each end of the threaded rods (see Figure 3), or limit the distance between the other edges of the tipplates and baseplates to 24 inches minimum.

3.4 CONNECTION OF STACK RESTRAINT BRIDLES

In order to facilitate a quasi hands-off deployment and reduce the dynamics caused by the one-g environment, a stack restraint system has been provided. It consists of three wire harnesses which connect the pivots on the eighth batten, from the base on each longeron, to the tipplate. They are released by pulling towards the tip (outward at an approximately 30-degree angle) on each of the three white release cords. They are NOT to be released until the mast has extended approximately 6 feet and erected the first bays in the base (see Section 4, Deployment). Although they were shipped engaged, they should be checked to make sure that the wire ends are inserted in the release and the cotter pins are in place. The three white cords should be hanging downward and may be extended, if necessary to be activated, by someone at ground level. Care should be taken that the weight of cord necessary should not exceed the disengagement force of the cotter keys. It may be necessary to further spread the keys to ensure that they stay engaged (see Figure 4).

3.5 REMOVAL OF RESTRAINING RODS

The final step in preparation to operate is the removal of the three threaded rods holding the tipplate and baseplate rigidly apart. The outer nuts on all three rods sould be backed out evenly. If there is still considerable tension just as they are ready to release, the lanyard should very carefully be taken in approximately 1/4 inch to remove the load from the rods. This is done by switching the control box to "BRAKE" and "IN." The Variac may then be set to zero voltage and plugged in. Set the switchbox to "RUN." Advance the Variac very slowly just until the winch begins to turn. After only 1/4 inch of retraction return voltage to 0 Vac. The mast is now being supported by the lanyard and the threaded rods may be removed (see Figure 5). To continue deployment, switch to "BRAKE" and "OUT" and then back to "RUN."

SECTION 4: DEPLOYMENT

The deployment sequence can be divided into three distinct phases:

1. Phase 1: Initial Extension and Batten Adjustment (L = 0 to 5 feet) - Using a voltage of 40 Vac, the mast should extend easily. Extend the tipplate approximately 5 feet and/or until the first several battens at the base begin to curve. At this point stop the deployment and manually adjust the battens by "flipping" each section so that all the battens are curved with their convex side towards the baseplate. (Once started properly, this pattern will continue indefinitely until the unit is again fully retracted.) (See Figure 6.)

2. Phase 2: 5 feet to 7.5 feet ("Snapover") - Continue deploying. Observe closely the deployment dynamics for any abnormal event. As the mast is deploying at about 6 feet out, the three wire tethers become taut and gently pull the first bay erect. When this occurs, there is both rotary and axial motion of the stack as it assumes a new configuration. This is characteristic of all lanyard-deployed Astromasts. As soon as this "snapover" occurs, STOP DEPLOYMENT.

   At this point, approximately 7.5 feet of deployment, manually pull the white tethers downward (see Figure 7) and outward at approximately a 15-degree angle. They will pull out of the mast and drop. Continue pulling until all three wire bridles are free and clear from the mast and have dropped about 2 feet below the tipplate (see Figure 8).

3. Phase 3: Normal Deployment - In this mode the mast is now capable of being fully extended. Because there is no limit switch, the winch must be switched to "BRAKE" after the tip bays fully deploy.

4. Phase 4: Retraction - To retract, turn the input voltage to 0, select "BRAKE," and switch to "IN." Switch to "RUN" and increase power to approximately 55 Vac to initiate the tip retraction. Once the helix has been formed, the mast may be retracted fully. A lower input voltage should be selected so that the rate of retraction is about 1 inch per second. "Snapover" occurs when the tipplate is approximately 7 feet away and is again accompanied by rotary and axial movement of the stack. If the mast is not retracted to this point, it may be cycled indefinitely from 7 feet plus to 50 feet with no further adjustments. If "snapover" is allowed to occur, battens may have to be readjusted for normal operation. Astro has determined that the mast may operate with asymmetrical or wrongly flipped battens, but if they all operate identically, much lower internal loads are developed.

5. Phase 5: Stowage - As stated earlier, DO NOT ALLOW THE MAST TO RETRACT UNCONTROLLED INTO THE BASEPLATE. THERE IS NO RETRACT LIMIT SWITCH AND SERIOUS DAMAGE WILL OCCUR. Lower the input voltage as the mast reaches full retraction and gradually "creep" the tipplate to its final position. Stop deployment as soon as the three rods placed between the tipplate and baseplate extend from both the baseplate and tipplate through the mounting holes in each or until the average distance between the outer edges of the end plates is 24 inches. Each rod should have two nuts at each end on either side of the end plate so they may be joined to hold the plate securely. Once all 12 nuts are tightened, the stack is totally restrained and the mast assembly may be removed. DO NOT ATTEMPT TO DISMOUNT THE MAST ASSEMBLY WITHOUT THE RESTRAINING THREADED RODS HOLDING THE TIPPLATE AND BASEPLATE APART AND SECURELY FASTENED.

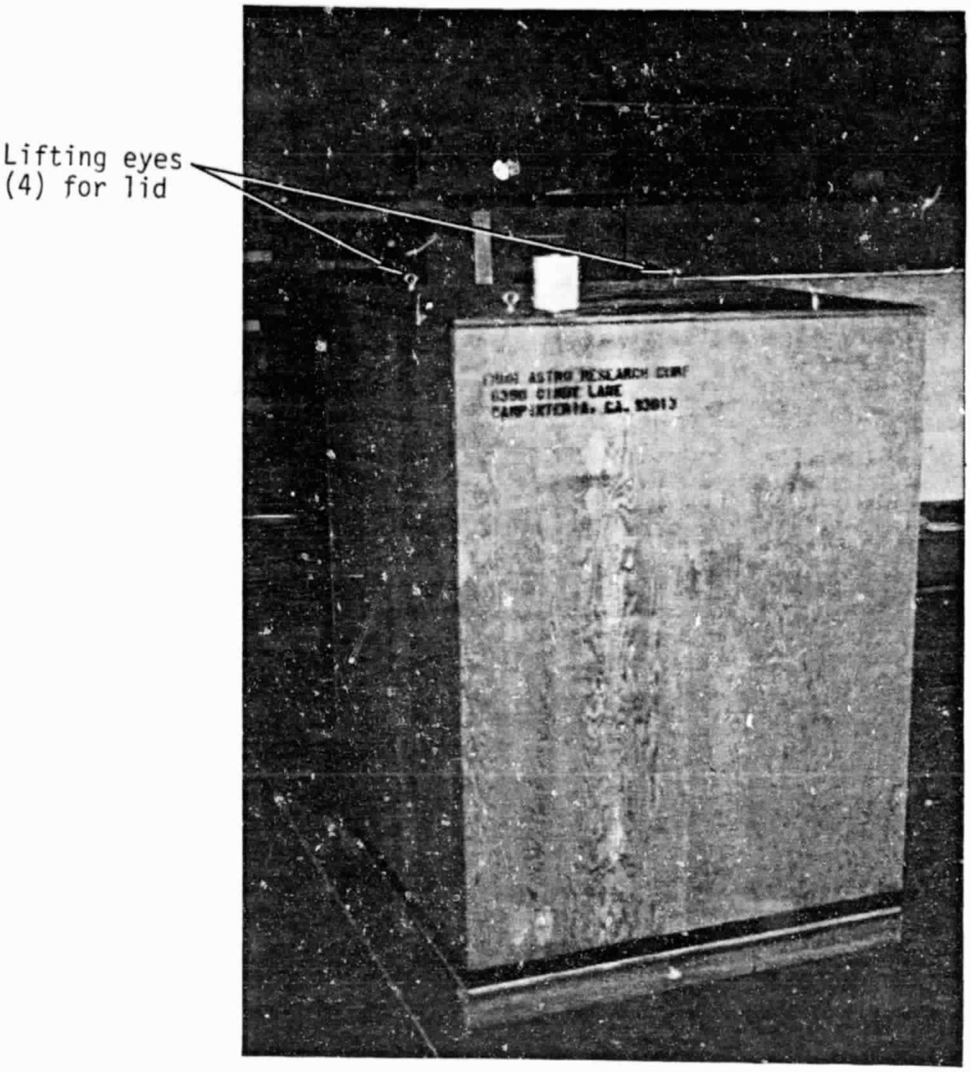
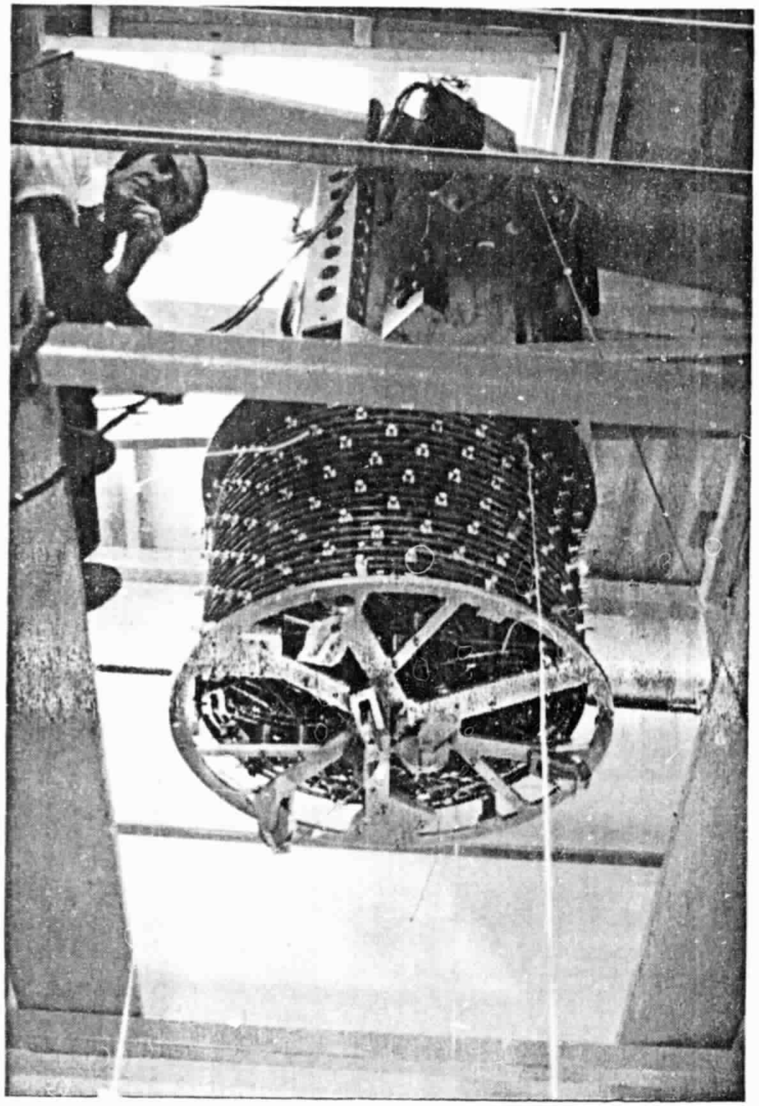
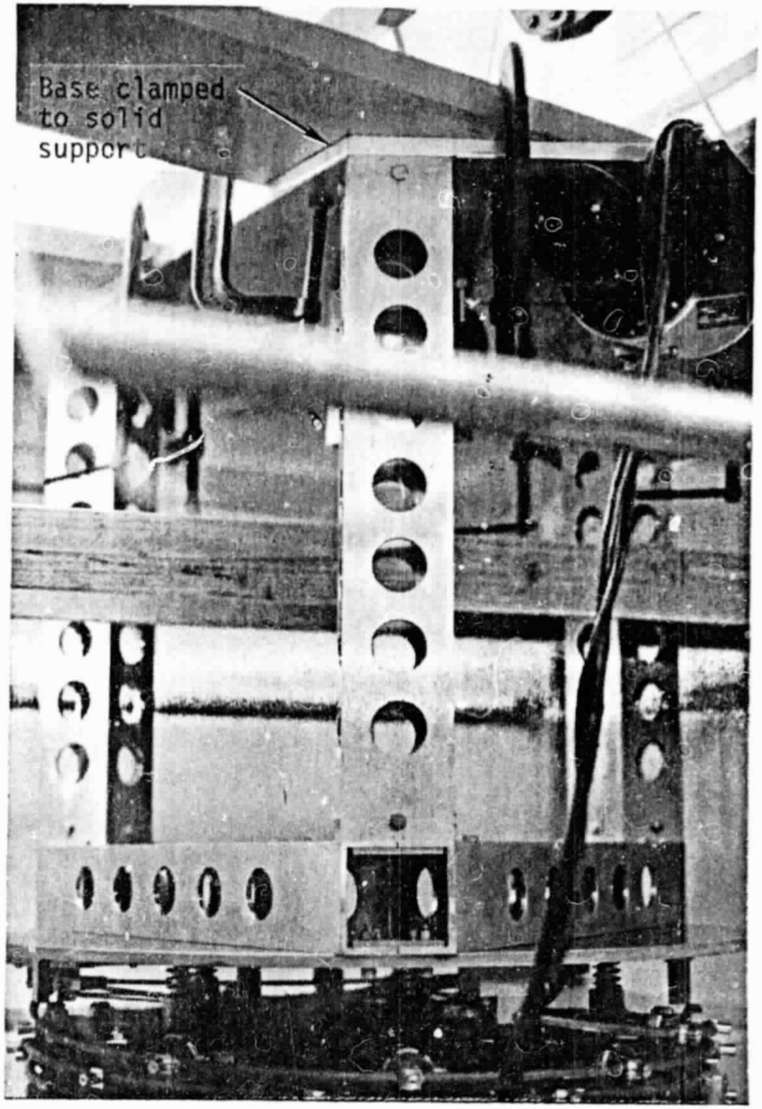


Figure 1. Shipping container.

P052



P053



P054

Figure 2. Unit shown mounted for vertical downward operation.

Figure 3. The threaded retaining rods are an indication of the nominal stack height.

P055

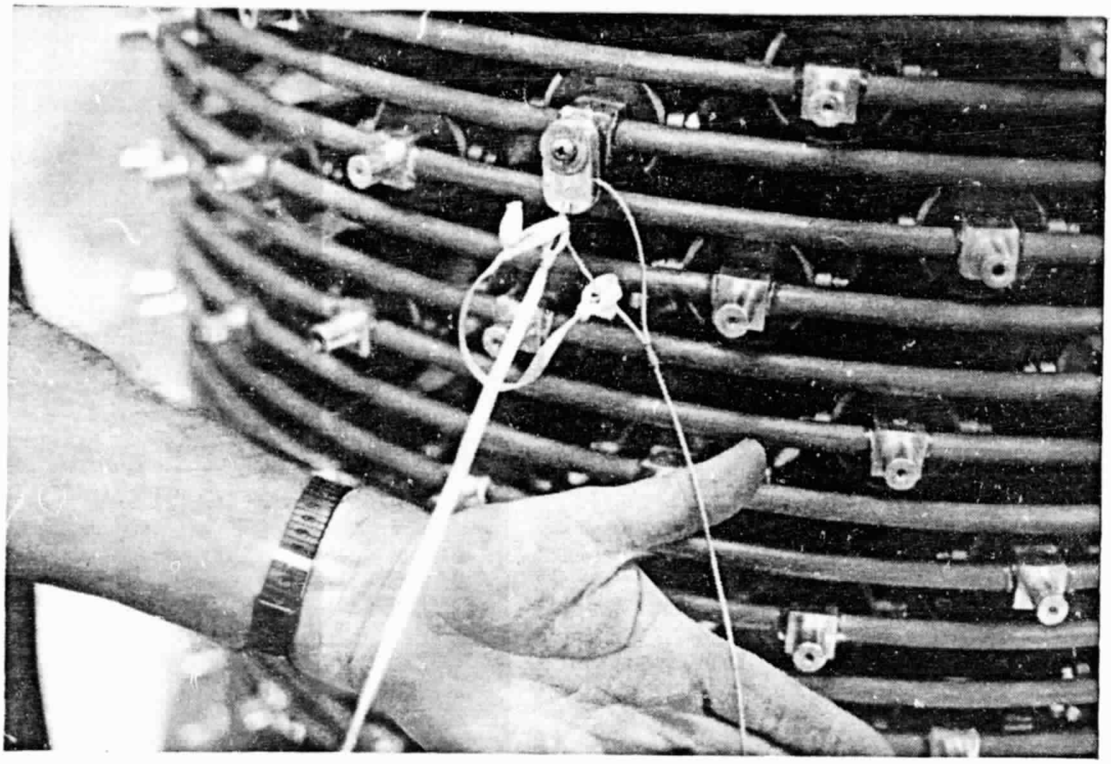


Figure 4. Stack restraint bridle installed. P056

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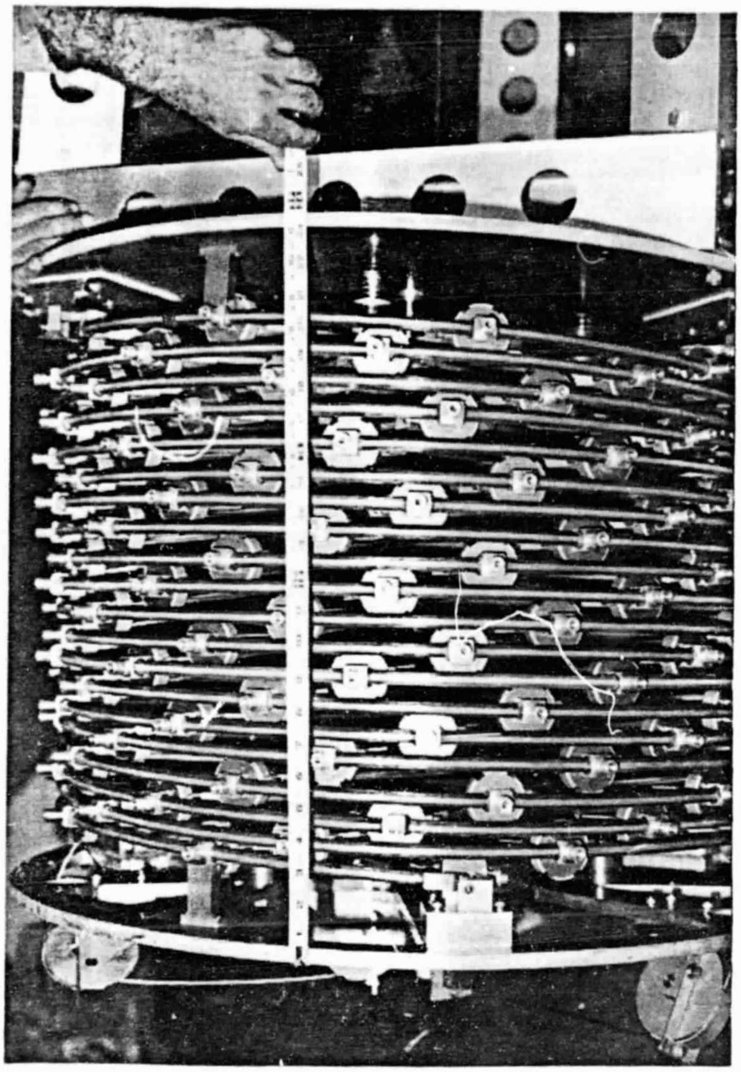
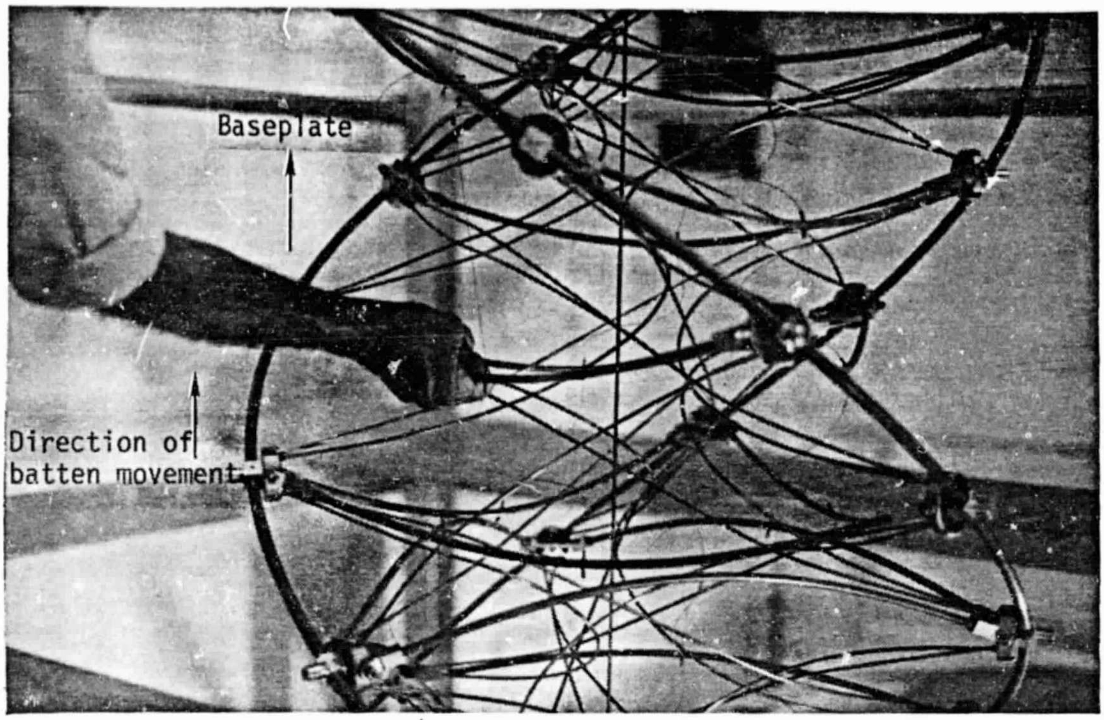
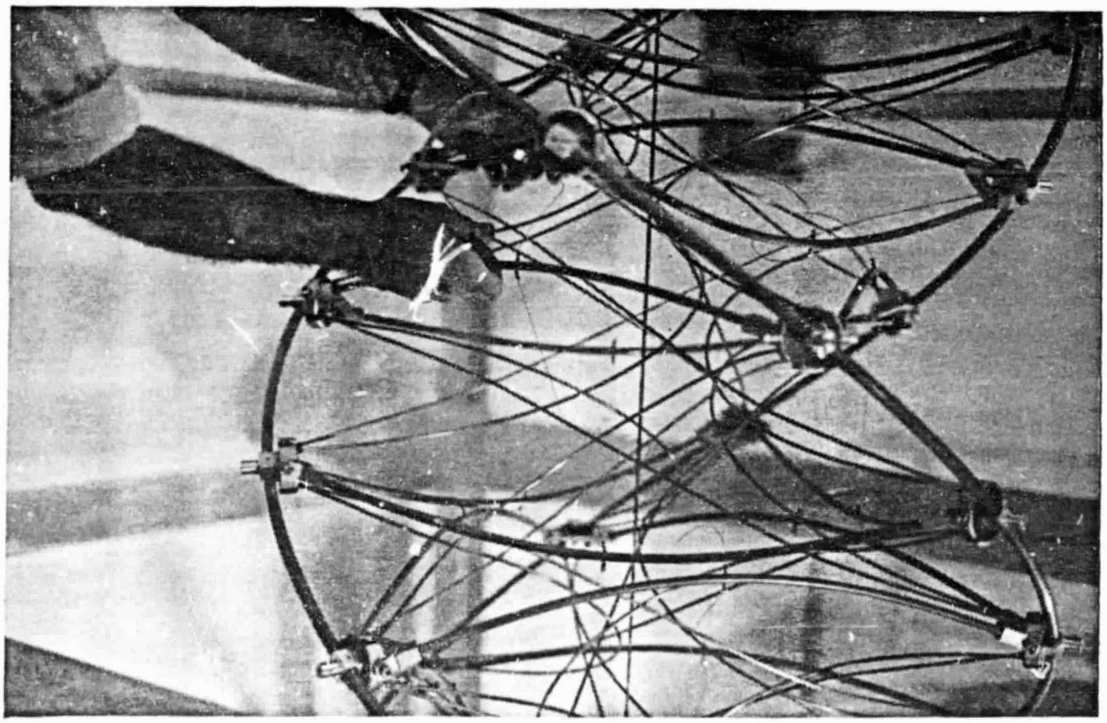


Figure 5. Restraining rods have been removed. P057



Before repositioning P058



After repositioning P059

Figure 6. Deployment stopped at 5-foot extension to reposition the batten frames for uniform direction of curvature (mast shown prior to "snapdown").

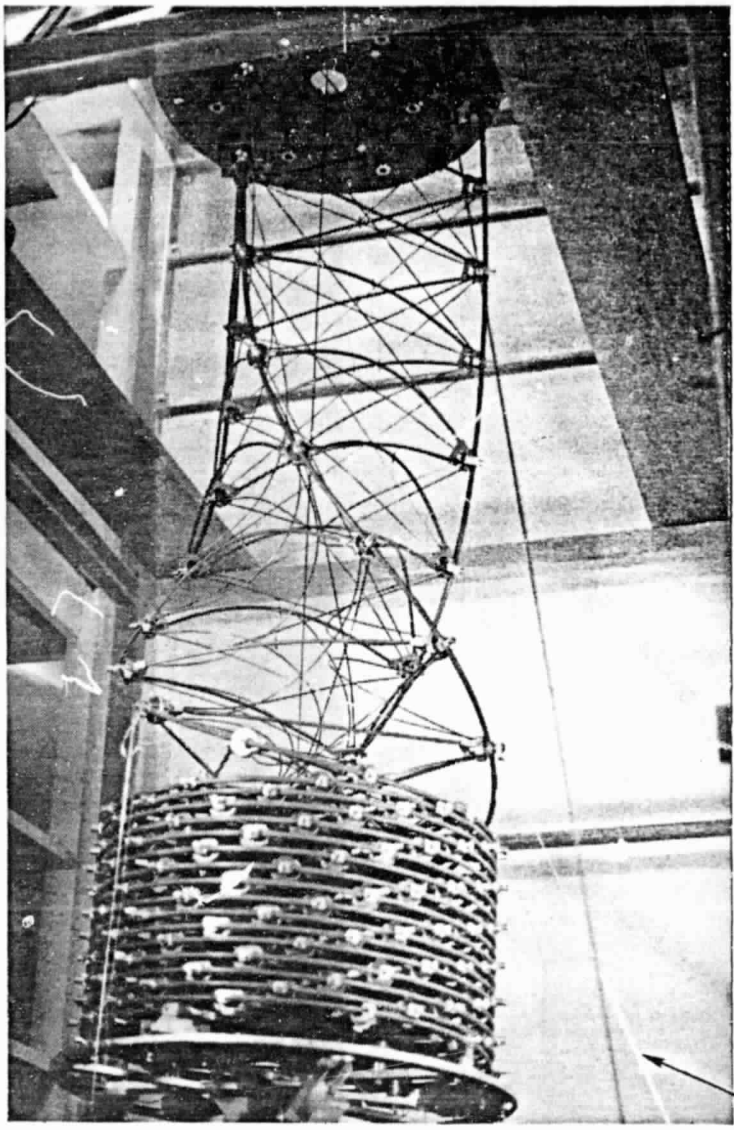
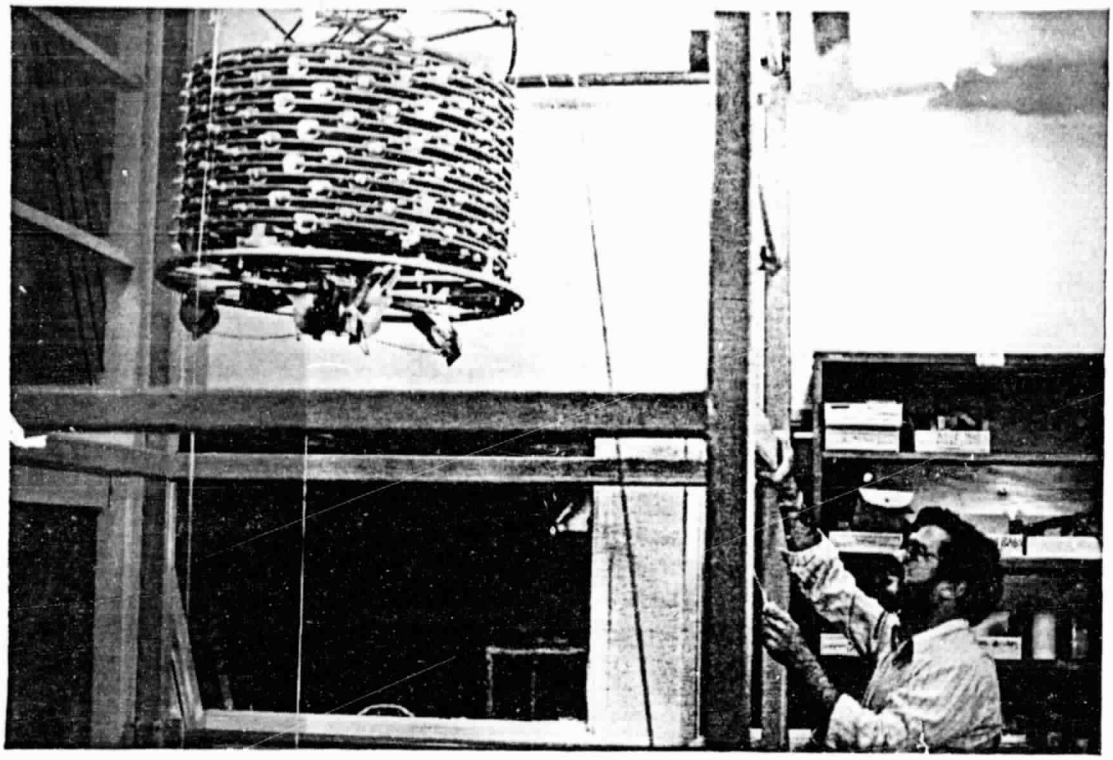
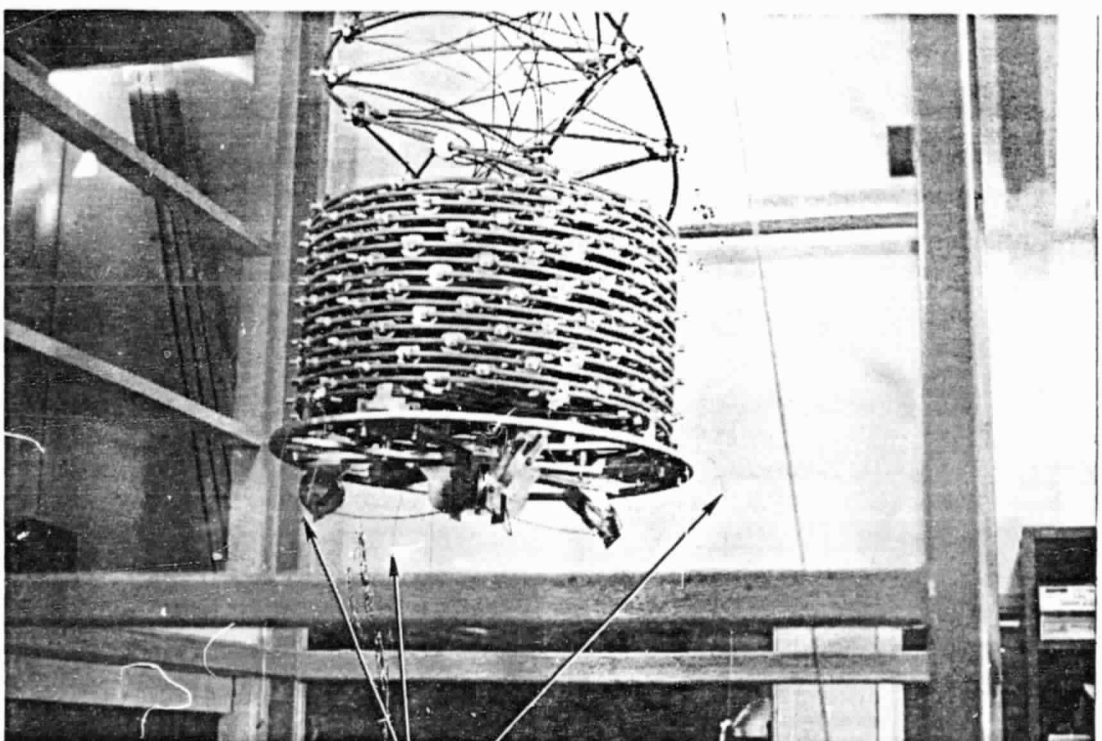


Figure 7. Just after "snapover." Note correct orientation of all batten frames (convex side to baseplate). *P060*



Pulling on tether to release pin *P061*



Bridles hang free after release *P062*

Figure 8. Release of stack restraints. Unit may now be fully extended and/or retracted without further assistance.

APPENDIX B

PROPERTIES OF THE 15.24-m- (50-foot) LONG SUPERMAST

PARAMETER	
D'ameter, D	0.75 m (29.53 in.)
Bay length, ℓ	0.4688 m (18.456 in.)
Longeron	
Circular cross section	
$\bar{d}$	0.0113 m (0.4447 in.)
A	1.002×10^{-4} m^2 (0.1553 in^2)
I	8.004×10^{-10} m^4 (1.920×10^{-3} in^4
$\bar{E}_\ell$	60.9 GPa (8.833×10^6 psi)
$(EI)_\ell$	48.74 N-m^2 (16,960 lb-in^2
Batten	
Circular cross section	
D_b	0.00787 m (0.310 in.)
I_b	1.883×10^{-10} m^4 (4.533×10^{-4} m^4)
E_b	57.4 GPa (8.33×10^6 psi)
$(EI)_b$	10.81 N-m^2 (3780 lb-in^2)
$(EI)_b/(EI)_\ell$ (nominal = 0.24)	
Diagonal	
Circular cross section	
D_D	3.68×10^{-3} (0.145 in.)
A_D	1.064×10^{-5} m^2 (0.01651 in^2)
I_D	9.002×10^{-12} m^4 (2.17×10^{-5} in^4)
E_D	5.77 GPa (8.37×10^6 psi)

PARAMETER

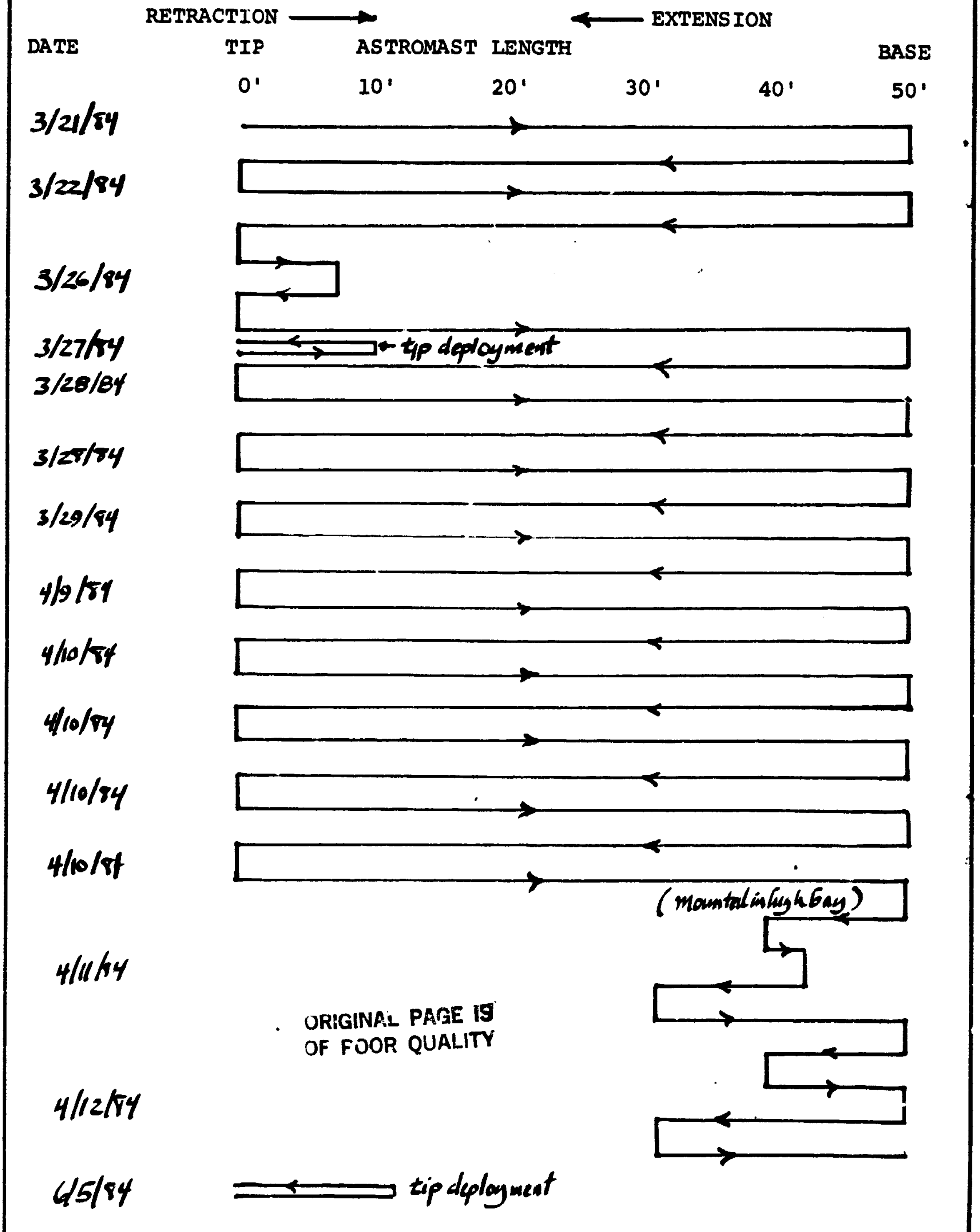
Local Euler buckling (single-laced mast)	2189 N (491 lb)
$P_{cr} = \frac{\pi^2 (EI)_\ell}{\ell^2}$	
Local Euler buckling (double-laced mast)	8753 N (1964 lb)
$P_{\ell d} = 4\ P_{cr}$	
Mast stiffness	1.287×10^6 N-m^2 (4.486×10^8 lb-in^2)
$(EI)_m = \frac{3}{8} D^2\ (EA)_\ell$	
Mast axial strength $= 3 \times P_{\ell d}$	25,182 N (5655 lb)
Mast bending strength $= P_{\ell d} \times \frac{3}{4} D$	4722 N-m (41,748 in-lb)
Diagonal angle, $\beta = \tan^{-1} \frac{2}{\sqrt{3}} \left(\frac{\ell}{D}\right)$	35.82 degrees
Batten force, $P_b = \frac{4\pi^2}{3D^2} (EI)_b$	253 N (57 lb)
Diagonal tension	156 N (35 lb)
$T_{dpre} = \frac{P_B}{2 \cos \beta}$	
Mast shear strength ($= 3P_B$)	759 N (171 lb)
Mast critical torque (double-laced mast)	284 N-m (2527 in-lb)
$Q_{cr} = \frac{2\pi^2}{D} (EI)_b$	
(neglects reduced strength battens at ends)	

PARAMETER	
Linear mass m, (calculated)	3.5 kg/m (0.196 lb/in)
(measured)	3.43 kg/m (0.192 lb/in)
Deployment force (calculated) $\frac{6\,EI_\ell}{D^2}$	519 N (116 lb)
Packaging ratio $\left(\frac{L\ retracted}{L\ deployed}\right)$, pivot to pivot	0.0307

APPENDIX C

RUN LOG AND CYCLES SHEET

Prepared	Name L. Finley	Date 6/6/84	ASTRO RESEARCH CORPORATION	Page of
Checked			TITLE CYCLE LOG FOR 50 FOOT SUPERMAST	Program
Approved				Job No. 41891



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ASTRO RESEARCH CORPORATION	CYCLES RECORD	EQUIPMENT LOG

NAME: 0.75m dia x 15m long Supermast | P/N: SK 2388 - 3 | S/N: 100

DATE	RETRACT	EXTEND	REMARKS	TOTAL
3/21/84	Full		Longeron S/N 001 Delaminated at end terminal, ½ bay long	½
3/21/84		Full	Longeron Repaired	1
3/22/84	Full		Repair Held, Mast left overnight & over weekend	1½
3/26/84		Full	Moved outside for photographs	2
3/26/84	8 Battens	8 Battens	Done vertically w/o a tether.	2'
3/26/84	Full		Done inside, horizontally	2½
3/27/84	10' TIP	10' TIP	Extended 10 FEET AT tip for transition stiffness. Pivot unbonded	-
3/27/84		Full	Repair Pivots 9 & 10 on S/N 001, Lubricated Diagonals	3
3/28/84	Full	Full	All Repairs Holding	4
3/28/84	Full		Retracted "Hands off" at base, left overnight	4½
3/29/84		Full	More loose pivots #6 & 64 on S/N 100, Repairs O.K.	5
			(Longeron S/N 100 Removed & all pivots Pull tested 765 lbs	
4/9/84	Full		Longeron S/N 100 Delaminated at Base terminal 1/2 B	5½
4/9/84		Full	All pivots holding. Repaired Longeron S/N 100	6
4/10/84	Full	Full	Used Stack dolly to support Stack	7
	Full	Full	OK	8
	Full	Full	OK	9
	Full	Full	OK	10
	Full		Left retracted overnight	10½
4/11/84		11 FEET	Mounted Vertically Downward in high bay Batten ft,	
	2 FEET		Realign Battens	
		TO 20'	Stack Restrained from Rapid transition	
	Full		Snaps over at 70" extension	
		23'	To Bottom of Pit, Stack Restrained again	
4/12/84	Full		Stopped & sized wires in Stack Restraint	
		12'	Self Deployed. Removed Stack Restraint	
	Full	23'	Filmed, Manual batten slipping at 5' Released 8'	
	23'		With film. After unit brought Down & Stored	
6/5/84	6'	6'	Extend to Set Length of Bridle stack tensioners	

ARC Form No. OC1014

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